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(54) Determining the position of a pile

(57) A method and apparatus for determining the position of a pile or ground treatment apparatus or of an elongate element, generally while the pile or the like is being driven into the ground by means of a hammer or the like, is disclosed.

The method involves measuring the time to receive the acoustic signal emitted due to the impact of the hammer on the object and comparing this with a reference signal. The difference in times will indicate the progress of the pile and hence the point at which it reaches the limit of its travel. A method of indicating ground conditions is also disclosed, involving the comparison of the time the stress wave induced in the pile takes to propagate up said pile with the propagation time of the partially reflected stress wave. This method can also be used to determine the depth of the pile below ground.

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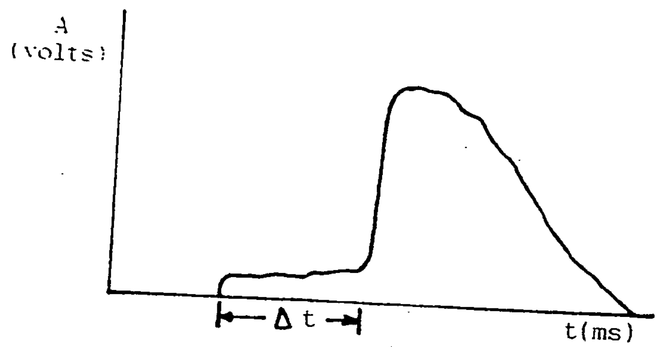

FIGURE 1

IMPROVEMENTS APPLICABLE TO PILING INSTRUMENTATION

This invention relates to a method and apparatus for determining the position of a pile or ground treatment apparatus or of an elongate element, generally while the pile or the like is being driven into the ground by means of a hammer or the like. For convenience, the invention will be described hereinafter in relation to its use in determining the position of a pile, although it will be appreciated that the invention is not restricted to this particular application. Typically, the location of the pile is measured with respect to a reference point which can be either readily measured or which is fixed with respect to the ground level. Through knowing this location the method allows the penetration of the pile into the ground per hammer blow to be monitored continuously.

Several instrumentation systems exist for monitoring the behaviour and characteristics of a device which is being driven into the ground. These require the connection of accelerometers and strain gauges to the device itself, which causes interruption to driving and the accuracy of these systems in terms of measurement of displacement is very poor. No system has yet been identified that can successfully perform this task by a method which does not require the attachment of detecting apparatus to the pile.

Since the advent of automatic pile driving plant, high hammer blow rates are common. However, during the installation of either a pre-cast pile or ground treatment system, interruptions occur to driving and hence hammer blows, in order to establish a height reference point on, say, the surface of the pile, to allow a known number of hammer blows to the pile and then to measure the penetration that has thereby been effected. This exercise needs to be repeated until a penetration per blow below a specified figure has been

achieved. An object of this invention is to eliminate these interruptions and provide continuous monitoring of the penetration per blow.

Another object of the invention is to monitor the instantaneous position of the top of a pile during a pile operation.

In accordance with one aspect of the present invention there is provided a method of measuring the position of a rigid, resilient object struck by a hammer or the like, wherein there is used detecting apparatus which is free from attachment to said object. In one embodiment, the method comprises comparing the incidence upon a detector of (a) a wave created by contact of said hammer with said object and (b) a reference signal.

There is also provided an apparatus for use in the method described above, the apparatus comprising a portable system comprising means for comparing the incidence upon a detector of (a) a wave created by contact of said hammer with said object, and (b) a reference signal.

In a pile driving operation, the driving force is generally provided by a hammer blow (typically a 5 ton hydraulically driven hammer of up to 1.5m drop height). Between 30% and 95% of the energy can be transferred into the pile or element to effect its penetration into the ground. The effectiveness of this transfer of energy is dependent upon the nature of materials (if any) employed as a cushion at the point of contact with the hammer. The remaining energy is lost, typically as heat and acoustic energy among others. The acoustic signal generated from the top of the pile may be detected electronically and this is utilised in methods hereinafter disclosed.

In one embodiment of the invention there is provided a portable system which is mounted on the driving rig of a pile-driving system and which operates in the following manner:

The airborne acoustic signal generated from the hammer/pile impact is detected using, for example, a microphone mounted above the hammer mechanism and suitably isolated from the leader/support structure. A suitable electronic circuit is employed to enhance the signal and compare its arrival time with a reference time pulse associated with the hammer blow. The time interval between the reference signal and the arrival of the airborne acoustic impulse can thereby be determined. As a result, the distance between the reference point and the detector may be calculated from the velocity of sound in air, typically 333 m/s. The measured time interval will increase as a pile is hammered into the ground and a processor type circuit may be employed to monitor the change of this time interval according to the number of hammer blows performed, and thus continuously monitor the penetration per blow.

The reference signal is advantageously obtained from one of the following means:

i) It is not uncommon for an automatic driving rig to provide an electrical signal in synchronism with the hammer blows. This may be used directly as the reference pulse and any constant delays between the electrical reference pulse and the detection of the airborne acoustic impulse may be removed by suitable calibration.

ii) An optical sensor may be placed close to the point of impact of the hammer in such a way as to produce an electrical impulse, thereby providing information as to when the hammer has been lifted above the detection point and also when the hammer impacts upon the pile head.

iii) In the case of a driving rig which uses a winch and a cable mounted hammer, a load sensor may be employed to detect cable or winch loading. The reference signal can be generated

electrically from this sensor and calibrated accordingly.

iv) The reference signal may be derived from a portion of the impact energy that is transmitted throughout the hammer supporting structure. This system would preferably be used with diesel or hydraulically driven hammers. A vibration detector, such as an accelerometer, may be placed either on the hammer cage or driving mechanism, and with suitable signal processing, the detector system can generate an electrical impulse which can be used as the reference signal.

Where the detector is located above the hammer at a fixed position on the leader mast, a correction for the time taken for the pulse wave to travel up the mast to the point of detection can be taken into account since the hammer mechanism travels down the mast as it is driving the pile into the ground. The simplest way of making this correction is to adjust the velocity of the airborne acoustic signal that is used for the calculation, as it is now the difference between the velocity in air and the velocity of the wave travelling up the structure of the mast.

It is therefore envisaged that portable bolt-on equipment, housing both the airborne acoustic detector and the structure dependent detector, can be located above the hammer system on the driving rig, such that it will provide the necessary data.

In a second embodiment, detection of the signal is achieved without attaching detecting apparatus to the driving rig. The reference signal is obtained from the system being driven into the ground (e.g. steel, concrete, etc) and may be, for example, the stress wave created by the hammer blow. The stress wave travelling down the pile, at 4-5 km/s in concrete, also acts as an acoustic source, although of lower amplitude.

A suitable detector, for example a microphone, located a known distance from the point of entry of the pile into the ground will first detect the airborne sound generated by the pile stress wave. This will typically remain until the airborne hammer blow sound is incident on the microphone, the amplitude of this second wave being considerably larger and easily distinguishable from the pile bound stress wave.

A suitable time measuring system, such as an oscilloscope or other electronic system, can be used to measure the time interval between these two signals. The height of the pile can be calculated arithmetically according to the respective paths and wave velocities.

For example, if the pile top was 10 metres above the detector, and the detector 1 metre from the base of the pile, the airborne acoustic signal caused by the hammer blow would take 30.180 ms to reach the detector. The stress wave will travel down the pile at a speed of, say 4000 ms^{-1}, setting up airborne acoustic signals as it propagates, these airborne acoustic signals being easily distinguishable from that produced directly from the hammer blow. It can be shown that the first such signal to impinge on the detector is that produced by the stress wave when it is 9.91646 m from the top of the pile, and the total time taken for the reference signal due to the stress wave to reach the detector is 5.496 ms. The difference of 24.684 ms is easily measured to a resolution of microseconds. Figure 1 illustrates a typical time/amplitude response obtained. The resolution of height can therefore be measured to the order of millimetres using conventional time measurement implements.

This method of detection may also provide a measurement of the depth of penetration of a pile into the ground without knowing the total length of the pile. This is due to at least partial reflection of the stress wave at the interface between the toe of the pile and the

ground into which it is being driven, due to the change of impedance at the pile toe. The signal caused by the reflected part of the stress wave as it propagates up the pile may be detected by the detector, and the time difference between detection of the original stress wave and the reflected portion thereof can be used to determine the depth of the pile below the ground. The ratio of the amplitude of the reflected portion of the stress wave to the amplitude of the original stress wave gives the amplitude reflection coefficient, which together with the impedance of the pile may be used to calculate the impedance of the ground directly below the toe of the pile. This gives an indication of ground conditions.

Further, if the electronic detection system is designed to discriminate the airborne, stress wave induced signal from the airborne hammer blow signal, a detector system can also be mounted on the plant at any location below the hammer.

CLAIMS:

1. A method of measuring the position of a rigid, resilient object struck by a hammer or the like, wherein there is used detecting apparatus which is free from attachment to said object.

2. A method according to claim 1, wherein said method comprises comparing the incidence upon a detector of (a) a wave created by contact of said hammer with said object, and (b) a reference signal.

3. A method according to claim 2, wherein said reference signal comprises an electrical signal from a driving rig which controls said hammer.

4. A method according to claim 3, wherein said electrical signal is provided in synchronism with the hammer blows by an automatic driving rig.

5. A method according to claim 3, wherein said electrical signal is provided by an optical sensor close to the point of impact of said hammer.

6. A method according to claim 3, wherein said electrical signal is provided by a load sensor serving to detect cable or winch loading in said driving rig.

7. A method according to claim 3, wherein said electrical signal is provided by a vibration detector mounted on said driving rig.

8. A method according to claim 2, wherein said reference signal is obtained from the object being driven into the ground.

9. A method according to claim 8, wherein said reference signal comprises a stress wave in said object, which stress wave is created by the hammer blow.

10. A method according to claim 9, wherein said reference signal comprises said stress wave followed by a sound wave through air.

11. A method according to claim 9, wherein the depth of penetration of said object into the ground is measured by detecting the part of said stress wave reflected from the bottom of said object.

12. A method of providing an indication of ground conditions at the bottom of a rigid, resilient object being driven into the ground by being struck by a hammer or the like, wherein the part of a stress wave reflected from the bottom of said object is compared with the original stress wave caused by a blow of said hammer or the like.

13. A method of measuring the position of a rigid, resilient object struck by a hammer or the like, substantially as hereinbefore described with reference to the accompanying drawing.

14. An apparatus for measuring the position of a rigid, resilient object struck by a hammer or the like, the hammer being supported in a driving rig, wherein said apparatus comprises a portable system comprising means for comparing the incidence upon a detector of (a) a wave created by contact of said hammer with said object, and (b) a reference signal.

15. An apparatus as claimed in claim 14, wherein the apparatus is adapted to be mounted on said driving rig without attachment to said object.

16. An apparatus as claimed in claim 14, wherein the apparatus is adapted to be positioned away from said object and from said driving rig.

Patents Act 1977
Examiner's report to the Comptroller under Section 17 (The Search Report)

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Relevant Technical fields

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(ii) Int Cl (Edition 5) G01S (11/14), E02D (7/14)

Search Examiner

J M MCCANN

Databases (see over)

(i) UK Patent Office

(ii) ONLINE DATABASE: WPI

Date of Search

17 MARCH 1992

Documents considered relevant following a search in respect of claims 1

Category (see over)	Identity of document and relevant passages	Relevant to claim(s)
X	GB 2149700 A (NRDC) See Figure 2	1
X	SU 1394388 A1 (KAZAMINING INST) Figure 2 and abstract	1

SF2(p)

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Category	Identity of document and relevant passages	Relevant to claim(s)

Categories of documents

X: Document indicating lack of novelty or of inventive step.

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